

## Possible Detection of Large Solar Particle Event at Balloon Altitudes during the 2001-2002 TIGER Flight

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### Abstract

The Trans-Iron Galactic Element Recorder (TIGER) was launched on December 21, 2001 and flew for about 32 days on a long-duration balloon mission from McMurdo Base in Antarctica. On December 26, 2001 at about 5:30 UT, a ground-level solar particle event (M7.6 flare) was observed by a number of neutron monitors. The SIS instrument aboard the ACE spacecraft measured the elemental composition and particle energy spectra up to  $\sim 150$  MeV/nuc. While not designed to operate under such conditions, TIGER data for the same period show interesting variations in the count rate and composition of the measured particles that may be related to the detection of heavy Solar particles (Si to Fe) in the  $\sim$  GeV/nuc range. We discuss the TIGER observations in relation to other available data from this event.

### 1. Introduction

The objective of the Trans-Iron Galactic Element Recorder (TIGER) experiment is the measurement of the elemental abundances of galactic cosmic ray nuclei with charge  $26 \leq Z \leq 40$ . These elements can help distinguish between a warm stellar atmospheric (FIP enhancement; e.g. [6]) and cold interstellar dust and gas (refractory enhancement; [3]) GCR source. For this purpose, several long-duration balloon flights from McMurdo, Antarctica, are planned for the balloon-borne instrument over the course of a few years. The first such flight commenced in December 2001 towards the end of the solar maximum and the  $\sim 32$  day period of data collection spanned the ground-level solar energetic particle (SEP) event starting at 5:30 UT on December 26, 2001. TIGER data gathered during the first five hours of this event show interesting deviations from the data gathered during the other time periods, suggesting possible detection of solar particles above 600 MeV/nuc. The TIGER instrument is described in more detail in [7] and [5]. Preliminary results for the heavy-element abundance measurements from the first flight will be presented elsewhere at this conference [5].

## 2. Data

The TIGER instrument was designed to trigger on heavy elements  $Z \gtrsim 13$  traversing the detector stack. The solar event created a net rise in raw triggers as shown in Figure 1. Because of confusion from low- $Z$  hits during this time the number of properly reconstructed particle tracks and thus properly identified particles actually decreases during these hours, since the position determination efficiency drops from  $\sim 80\%$  to under  $\sim 60\%$  during that time and the instrument encounters additional downtime.

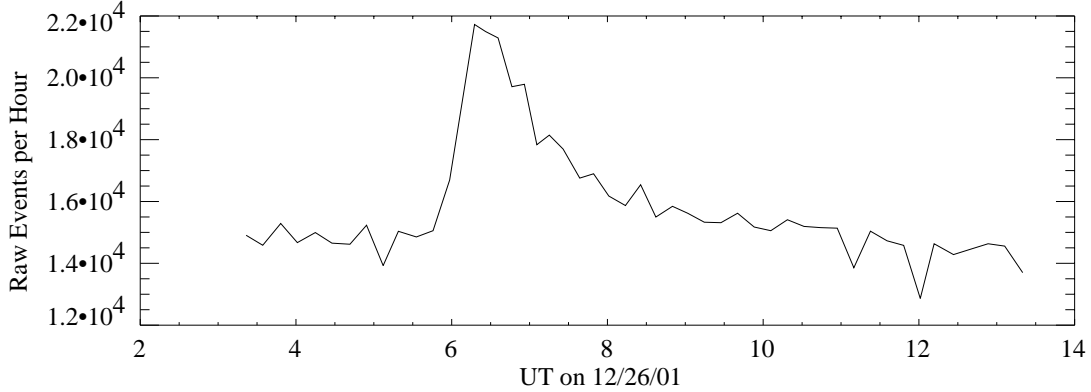


Fig. 1. Raw TIGER counts during SEP event (No dead time correction)

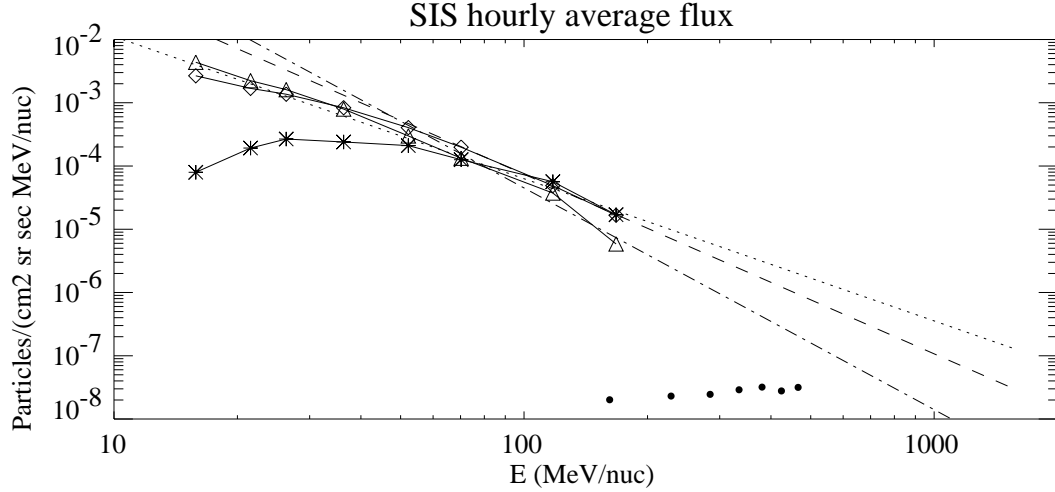
## 3. ACE & TIGER

The CRIS instrument [8] onboard the ACE spacecraft can be used to establish quiet-time GCR fluxes in the energy range of interest here. The SIS instrument [9], is also used to fix the low-energy ( $\lesssim 150\text{MeV/nuc}$ ) compositional data during the event.

Since the TIGER instrument has a residual atmospheric overburden of about  $5\text{g/cm}^2$  and  $5.2\text{g/cm}^2$  instrumental grammage to the lower Cherenkov counter, iron nuclei impinging on the atmosphere need to have at least  $\sim 650\text{MeV/nuc}$  to trigger the instrument at vertical incidence. This sets the lower limit of the lower TIGER energy range. The upper range starts where the particles can trigger the C0 Cherenkov detector around  $2.5\text{GeV/nuc}$ .

Figure 2 shows the total hourly-average iron spectra at zero, one and two hours into the SEP event as measured by SIS, together with an indication of the *galactic* CR flux as measured by CRIS at higher energies, averaged over the 27 days prior to this SEP event. The straight lines indicate linear fits to the three highest-energy channels of SIS as they extrapolate into the  $\text{GeV/nuc}$  region at zero (dotted), one (dashed) and two hours (dash-dotted).

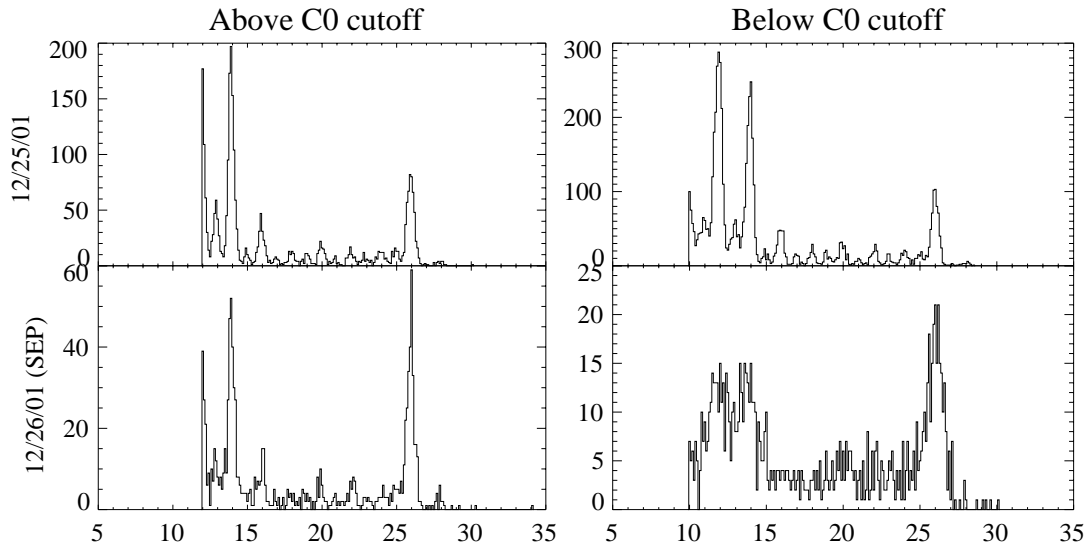
It is clear that it is at least possible that solar particles contributed to the measured TIGER fluxes for the first few hours of the event. This suggests study of the TIGER data during this time in order to attempt to extend the SIS measurements in energy by up to an order of magnitude.



**Fig. 2.** SIS Fe measurements: hourly averages 5-6UT (\*), 6-7UT (◊), and 7-8UT (Δ); CRIS quiet-time averages (●) and projections (dashed lines, see text)

For example, in the SIS energy range, the event showed an energy-dependent enhancement in Fe/O with more iron at higher energies; and a Fe/(S+Ar+Ca) ratio of  $\sim 4$  between  $\sim 10$  MeV/nuc and  $\sim 170$  MeV/nuc [2]. At 285 MeV/nuc, the CRIS instrument indicates  $\text{Fe}/(\text{S}+\text{Ar}+\text{Ca}) \approx 1.75$  [4] compared to the TIGER raw ratio of about 1 at  $\sim 1$  GeV/nuc under  $5 \text{ g/cm}^2$  of atmosphere. If the solar accelerator is indeed capable of accelerating iron into the GeV/nuc region, such an enhancement might be seen in TIGER.

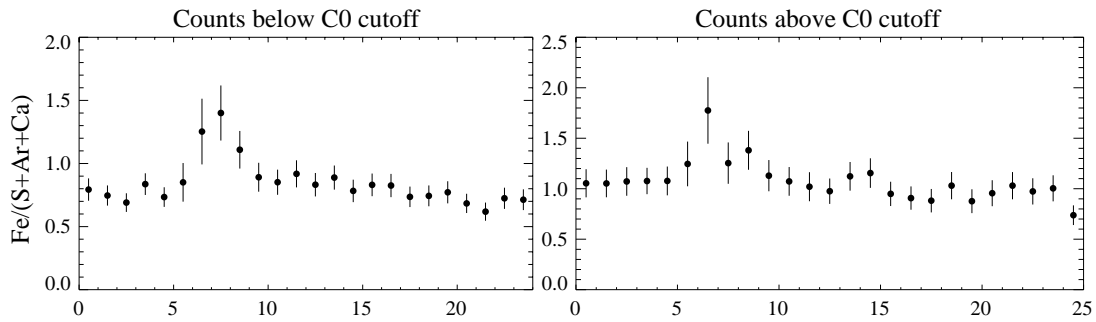
Figure 3 shows the measured charge histograms in the two TIGER energy ranges during the two hours of greatest activity and during the same time on the previous day. It is clear that resolution was degraded in the lower TIGER energy



**Fig. 3.** TIGER Z histograms during 6:10-8:15UT one day before and during the event

range as a result of confusion of events by low-Z particle background. This manifests itself in an absolute drop in the raw counts for each of the elements, which is an indication of the track-reconstruction problems during this time. However, the underlying algorithm was never designed to deal with these conditions. Preliminary research indicates that its efficiency can be improved if the known problems during this time are taken into account.

However, as also shown in Figure 4, both energy ranges do show more iron during the SEP event than before, more clearly seen in the higher-energy range, as there is less deterioration of resolution there. Figure 4 also indicates the shorter duration of the change in  $\text{Fe}/(\text{S}+\text{Ar}+\text{Ca})$  in TIGER in the higher energy range, as expected.



**Fig. 4.** Raw TIGER ratios vs. UT on 12/26 (statistical error bars only)

#### 4. Outlook

Our preliminary analysis shows that the ratio of  $\text{Fe}/(\text{S}+\text{Ar}+\text{Ca})$  for both the TIGER energy ranges is consistent with that observed by SIS, indicating that heavy ions during an SEP event might be accelerated to energies in the GeV/nuc range. Additional analysis of the TIGER data is required to see if the number of events rejected by our software selection can be reduced and to verify that the TIGER ratio is not an artifact of the high event rate.

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